



Development of augmented reality (AR) SI MOPEM to improve teachers' understanding of learning models

Hilda Dhaniartika Nurma'ardi^{*)}¹, Anna Maria Oktaviani², Ahmad Antoni³, Nida Nabilah Limas⁴

¹Universitas Primagraha, Serang, Indonesia; hildadhaniartika@gmail.com

²Universitas Primagraha, Serang, Indonesia; annamariaoktaviani222@gmail.com

³Universitas Primagraha, Serang, Indonesia; thony6053@gmail.com

⁴Universitas Primagraha, Serang, Indonesia; nidanabilahlimas2505@gmail.com

^{*)}Corresponding author: Hilda Dhaniartika Nurma'ardi; E-mail addresses: hildadhaniartika@gmail.com

Article Info

Article history:

Received October 04, 2025

Revised November 08, 2025

Accepted November 10, 2025

Available online November 19, 2025

Keywords: 21st century, Augmented reality, Learning model, SI MOPEM, Teacher understanding

Copyright ©2025 by Author. Published by Lembaga Penelitian dan Pengabdian kepada Masyarakat (LPPM) Universitas PGRI Mahadewa Indonesia

Abstract. Based on the analysis, many teachers experience limitations in understanding the syntax of learning models that impact the quality of teaching and student competency. Therefore, the development of AR media becomes an effective solution. This study aims to develop AR-based SI MOPEM (Learning Model Syntax) media. This R&D research was conducted using a 4D development model. The population of this study was all elementary school teachers in Serang Regency, whose samples were taken using purposive sampling of 50 people in the same cluster. Data collection techniques included observation, interviews, documentation, questionnaires, and tests, while the instruments were validity sheets, teacher understanding tests, and self-assessment questionnaires. Overall, the validity test was in the very feasible category, and a limited trial with 12 teachers found SI MOPEM very practical (91.46%). The results showed that the effectiveness test resulted in a significant increase in understanding (paired sample t-test, $p = 0.000$) with an n-gain score of 0.63

(moderate category). Therefore, it is concluded that SI MOPEM is highly feasible, practical, and effective as a tool for understanding learning models interactively and independently. This research recommends conducting larger-scale testing and further developing SI MOPEM, such as adding features or integrating it with other platforms.

Introduction

Education is a planned and systematic process to develop an individual's potential and qualities (Alimah et al., 2024; Maisyaroh et al., 2021; Oktaviani, Makrum, et al., 2023). The success of education itself is inseparable from the support of many parties, one of which is teachers as professionals who play a crucial role in the learning process (Liu & Phelps, 2020; Nurma'ardi & Kuswaty, 2023). The responsibilities of this role range from the ability and skills to transfer knowledge (Ahmadin et al., 2023), mastery of material and learning processes, philosophy (Arsyad & Sauri, 2024), conceptualization (Aryanto et al., 2022), to mastery of technical matters that can support a smooth learning process (Pujiarti et al., 2023). Like a domino effect, teacher readiness can influence the process and achievement of student learning outcomes (Chen & Yuan, 2021; Jensen et al., 2024). This means that when teachers are well-prepared, learning objectives are much more likely to be achieved optimally, and vice versa. Therefore, thorough preparation is essential (Astuty & Suharto, 2021).

This readiness can be reflected, among other things, in teachers' skills in selecting the use of learning models to facilitate students' enjoyable, meaningful, and high-quality learning experiences and climates (Budirahayu & Saud, 2023; Oktaviani, Nurma'ardi, et al., 2023). Moreover, the many variations of learning models indirectly increase teachers' freedom to determine which ones are most effective according to their needs. Unfortunately, many teachers still underutilize the diversity of learning models (Laia, 2023). This is due to various factors, including teachers' lack of understanding of the characteristics and syntax of existing learning models. Teachers often forget the steps involved in implementing them (Yusriani et al., 2020). This leads to a monotonous learning process, as teachers rely more heavily on lecture methods, which impact student engagement, abilities, skills, and learning outcomes (Mirza et al., 2025).

Similar to the findings from observations in March at SDN Baros 3, many teachers did not use a variety of learning models due to their limited ability to understand and select effective learning models. Ultimately, teachers encountered problems such as suboptimal student competency. Because interesting learning plays an important role in supporting the quality of learning (Alimah et al., 2024; Ernawati et al., 2024). In the process, teachers do know that there are many variations of learning models, but they have not yet fully understood them in depth (Zetriuslita & Alzaber, 2021). This is because explanations of learning models are mostly presented in written form. In addition, there is socialization or training that has not provided maximum support due to limited time and implementation conditions (Yusriani et al., 2020). This makes teachers less motivated to implement it and more focused and comfortable using simple learning methods and models without existing syntax dialogue.

In fact, a deep understanding of learning models gives teachers the freedom to create meaningful learning by adapting to learning needs such as linking materials, student and teacher characteristics, and situations (Aminah et al., 2022; Irwanto & Nisa, 2022). Previously, many researchers have studied this problem, but in fact, the research has only focused on students, namely presenting alternatives to using certain learning models to teachers, which are not necessarily effective in dealing with different conditions. If we look further, what needs to be done is to improve teachers' in-depth understanding of learning models so that they are more skilled and solution-oriented in selecting and considering their use according to their needs, so that learning is more meaningful and of higher quality (Nguyen et al., 2022). Therefore, an effective alternative solution is needed to address this need, namely the development of AR media to provide a visualization of the syntax of learning models. As a mixed reality, AR provides a visualization that makes it easier for someone to learn something because it indirectly creates a sense of presence and perception of what is displayed (Lambrecht et al., 2025; Santoso, 2021).

In line with Piaget's constructivist theory as proposed by Rosidah et al. (2024), constructing one's own knowledge through real-world experiences involving objects and simulations can foster deeper understanding than simply reading a textbook. Therefore, through its application, AR can increase motivation and understanding, allowing students to delve deeper into what they are learning (Asoodar et al., 2024; Gandolfi & Ferdig, 2025). Furthermore, research by Carolina (2022) also shows that the use of AR can increase active engagement and enthusiasm in learning.

The novelty of this research lies in the development of the MOPEM Information System (SI MOPEM) as an effort to address issues related to teachers' understanding of the syntax of learning models. Teachers who possess a deep understanding and skill in applying learning models will undoubtedly impact the quality of learning and student competency. Although the development of AR media has advanced rapidly and begun to enter the educational world, there has been no AR integration specifically for teachers to illustrate the syntax of learning models. The use of AR is

generally limited to explaining material to students. Therefore, this research offers an innovative use of the MOPEM Information System (SI MOPEM) as an effective solution.

Furthermore, AR technology allows users to use it anytime and anywhere, especially through visual feedback, which indirectly provides a sense of presence and communication, helping to enhance a deeper understanding for users (Li et al., 2025; Yang et al., 2021). This certainly aligns with the goal of the fourth SDGs, namely, equal access to and quality of education. For this reason, based on the problems that have been described, researchers are ultimately referred to review and find solutions that are expected to be more effective in improving teachers' understanding of learning models, namely by developing AR SI MOPEM media to improve teachers' understanding of learning models that cover the 21st century.

Method

Research Method and Design

This research is a type of R&D research with a 4D model (Define, Design, Develop, and Disseminate) using a mixed methods approach, combining qualitative and quantitative approaches (Pratama & Sukirman, 2023). The qualitative approach was used to explore needs, conduct expert validation, and describe the findings, while the quantitative approach was used to test the feasibility, practicality, and effectiveness of the developed product.

Participants and Sampling Technique

The population in this study was elementary school teachers in Serang Regency. The research sample was determined using a purposive sampling technique, which selects samples based on specific considerations. The consideration used was schools within the same cluster. The research sample consisted of 50 elementary school teachers from five schools: SDN Baros 1, SDN Baros 2, SDN Baros 3, SDN Sumur Peuteuy, and SDN Sidamukti 1.

Research Procedures

Define

Activities were conducted to analyze needs through observations and interviews with teachers regarding field issues. Furthermore, a literature review was conducted to strengthen the theoretical foundation and determine the direction of product development.

Design

Researchers developed an initial product design, validation sheet, teacher self-assessment questionnaire, and comprehension test instruments.

Develop

At this stage, the product design entered the creative process based on the design and concept that had been created. The finished product was then entered into the validation process to receive feedback and constructive criticism to refine the product. Then, the product deemed feasible was tested with a limited group to assess its practicality.

Disseminate

Products that had been declared feasible, practical, and effective were socialized to target schools and published for broader use by relevant parties.

For further details, the procedure for this research can be seen in the following image:

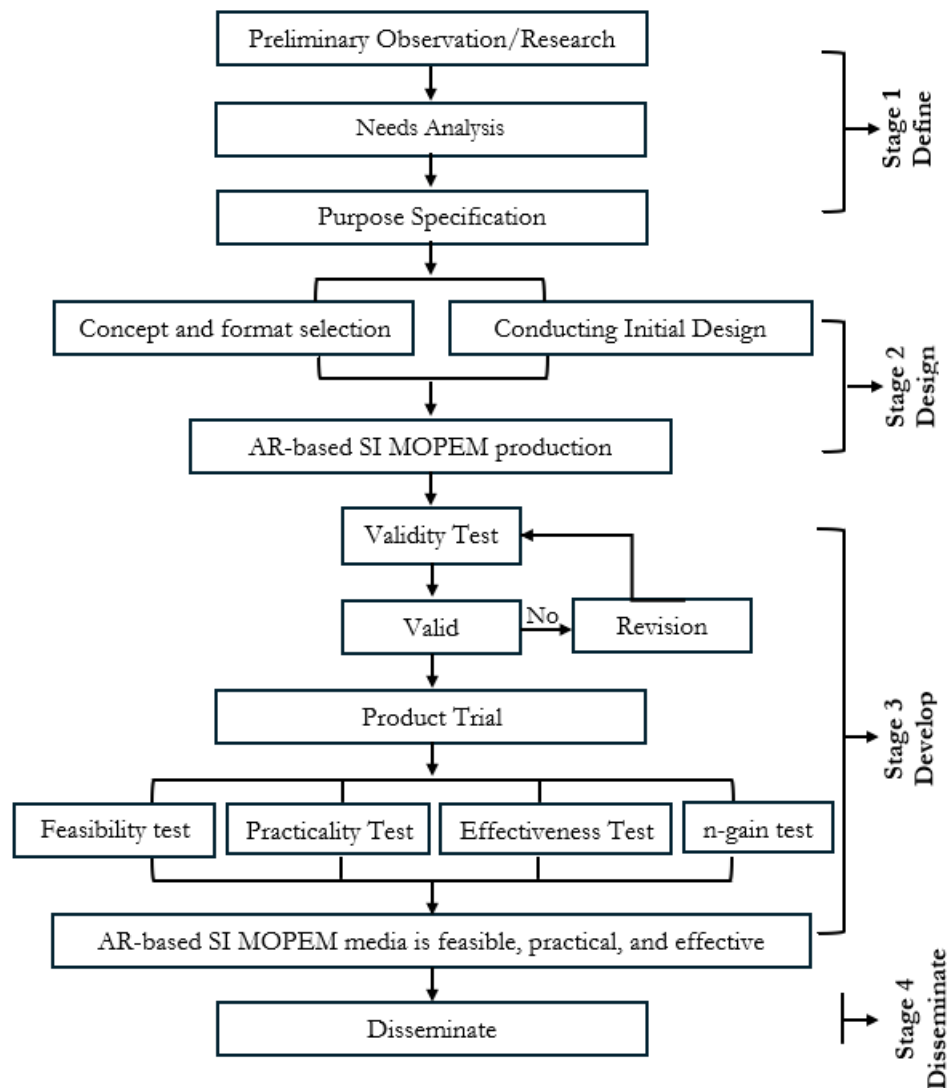


Image 1. Product Development Flowchart

Data Collection Techniques and Research Instruments

The data collection techniques included observation, interviews, documentation, questionnaires, and teacher comprehension tests. To ensure the instruments were accurate and targeted, the instrument grid was developed based on the research indicators and objectives, as shown in the following table:

Table 1. Observation Grid

No	Observed Aspect	Observation Item Number
1	Teachers' understanding of 21st-century learning models	1
		2
		3
2	Implementation of 21st-century learning models	4
		5
		6
3	Use of technology in learning	7
		8
		9
4	Need for innovative learning media	10

Table 2. Interview Grid

No	Observed Aspect	Question Item Number
1	General understanding of 21st-century learning	1
2	Understanding of 4C skills (Critical thinking, Communication, Collaboration, Creativity)	2
3	Readiness to implement 21st-century learning models	3
4	Implementation of innovative learning models in the classroom	4
5	Authentic assessment strategies	5
6	Use of technology in learning	6
7	Need for innovative learning media	7
8	Perspective on Augmented Reality (AR)-based media	8
9	Challenges faced by teachers	9
10	Hopes and suggestions for the development of SI MOPEM media	10

Table 3. Teacher Understanding Self-Assessment Instrument and Questionnaire Grid

Teacher Understanding Indicators		Test Instrument Grid		Questionnaire Grid	
No	Understanding Indicators	Sub-Indicators	Total	Sub-Indicators	Total
1	Translasi	Teachers can translate learning steps into methods/strategies into innovative learning process activities.	4	Give another example Interpreting	4
2	Interpretasi	Teachers can interpret the strengths and weaknesses of each innovative learning model.	4	Classifying Explaining	4
3	Ekstrapolasi	Teachers can predict potential changes when using an innovative learning model.	4	Predicting/drawing conclusions	4

Table 4. Validity Test Instrument Grid

No	Validated Aspects									
	Instrument Tes	Qty	Kuesioner	Qty	Media	Qty	Materi	Qty	Language	Qty
1	Material Aspect	3	Concept	1	Learning	5	Content Quality	4	The pattern used is clear	4
2	Construction Aspect	4	Construction	3	Media	5	Learning Goal Alignment	4	Communicative	6
3	Language Aspect	4	Language	3	Design	5	Feedback and Adaptation	2	The writing is consistent and follows the rules of the language.	4
							Motivation	1		

Data Analysis Techniques and Criteria

The data collected in this study were analyzed qualitatively and quantitatively. Qualitative data analysis was conducted descriptively to describe the expert validation results, teacher responses, and field findings. Meanwhile, quantitative data analysis was conducted to test the instrument's feasibility, using validity and reliability tests based on a Likert scale in SPSS. The instrument, which experts had tested, was summarized as scores and categories. Interpretation of the feasibility percentage values refers to the criteria shown in the following table:

Table 5. Eligibility Criteria

Interval (%)	Kriteria
$80\% < X \leq 100\%$	Very Eligible
$60\% < X \leq 80\%$	Eligible
$40\% < X \leq 60\%$	Fairly Eligible
$20\% < X \leq 40\%$	Not Eligible
$0\% < X \leq 20\%$	Very not Eligible

Source: [Aini & Fathoni \(2020\)](#)

The validated instruments and media were then tested for practicality using teacher self-assessment questionnaires on a Likert scale. Effectiveness was measured with a one-group pretest-posttest design, comparing teachers' understanding before (pretest) and after (posttest) using the product. Data analysis included prerequisite tests (normality), paired-samples t-tests to examine pretest-posttest differences, and N-Gain calculations to determine the level of improvement in teacher understanding, all conducted in SPSS.

Product Specifications

The developed product is an Augmented Reality-based media called SI MOPEM (Learning Model Syntax) in the form of an Android application. This media is designed to help teachers deeply and independently understand the syntax of learning models, anytime and anywhere. Users install the application and point the camera at the markers provided in the SI MOPEM handbook. The interface and usage of the application are shown in Image 2.



Image 2. AR SI MOPEM



Image 3. AR SI MOPEM Card Marker

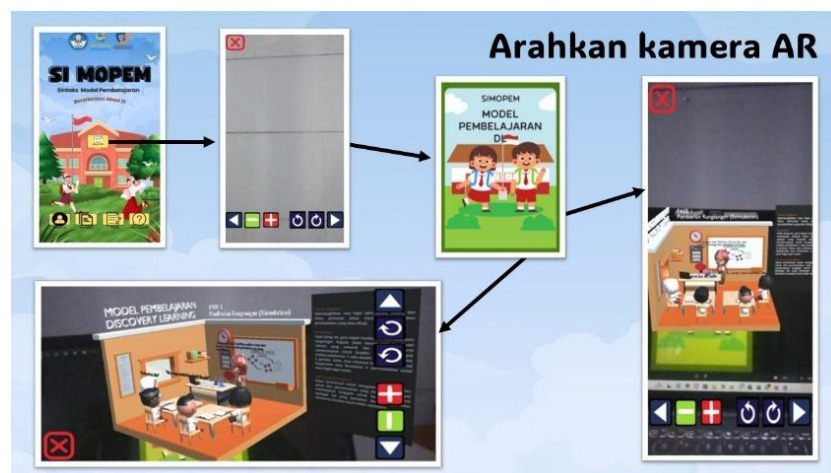


Image 4. How to use



Image 5. SI MOPEM Display

Results and Discussion

Define

The define stage is the initial step in the media development process, focusing on a needs analysis to identify problems in the field. Based on observations and interviews with elementary school teachers in Serang Regency, most teachers were familiar with various learning models, such as Project-Based Learning (PBL) and Discovery Learning (DL). However, their understanding of the characteristics and syntax of each model remained limited. This finding aligns with (Yusriani et al., 2020), who stated that teachers often forget or lack understanding of the steps in the learning model syntax, leading them to revert to lecture-based methods that are simpler and do not require 21st-century skills. A similar situation was observed at SDN Baros 3, where teachers faced challenges such as low student engagement, weak critical thinking skills, and suboptimal learning outcomes. The contributing factors included incidental, shallow teacher training, leaving teachers with insufficient time to explore or effectively practice implementing learning models (Yusriani et al., 2020).

In addition, interviews with five teachers at SDN Baros 3 reinforced these findings. The teachers recognized the importance of 21st-century learning, which emphasizes the 4C skills (Critical Thinking, Creativity, Collaboration, Communication), but its implementation remained limited due to a lack of supporting media, time constraints, and limited digital literacy skills. Some teachers had attempted to implement PBL and DL, but not consistently. Technology use was still basic, such as PowerPoint and learning videos, and none had used Augmented Reality (AR)-based media. The teachers expressed high enthusiasm for the development of SI MOPEM (Learning Model Syntax) media and hoped it would help them understand the steps of 21st-century learning models in a visual, interactive, and easily accessible way.

The results of the literature review further support this analysis, indicating that a deep understanding of learning models is a crucial factor for teachers in designing meaningful and 21st-century relevant learning experiences (Budirahayu & Saud, 2023; Oktaviani, Nurma'ardi, et al., 2023). Thus, the main need identified is not only knowledge of learning models but also a thorough understanding of their syntax and characteristics. Accordingly, the development of the AR-based media "SI MOPEM" is expected to provide concrete visualizations and engaging learning experiences, thereby enhancing teachers' independence in understanding, selecting, and implementing 21st-century-oriented learning models.

Design

The design stage is the second phase in media development, aimed at creating an initial product based on the needs analysis conducted during the define stage (Akram & Maryam, 2021; Lestari et al., 2023). In this stage, the researchers begin drafting the initial design of the AR SI MOPEM media as well as the instruments to measure its feasibility, practicality, and effectiveness. The design focuses on teachers' needs for a media tool capable of visualizing the syntax of 21st-century learning models in a tangible and interactive way. The product is developed as an Android-based Augmented Reality (AR) application, where teachers can scan markers to display three-dimensional animations of the steps of learning models such as PBL, PjBL, and DL, complete with supporting text explanations. Next, the researcher developed a research instrument that included a teacher response questionnaire and a teacher comprehension test. Therefore, the validation results obtained from this instrument will serve as the basis for revisions, ensuring that the developed product and instrument are truly feasible before being tested in the next development stage.

Development

The development stage is the third stage in the 4D model, focusing on the process of developing the initial product into a ready-to-use product through a series of validations, revisions, limited trials, and effectiveness testing. At this stage, researchers ensure that the designed AR SI MOPEM media is truly feasible, practical, and effective before disseminating it to target schools. The first step in this stage is expert judgment and user validation of the developed product, involving three categories of experts: material experts, media experts, and linguists.

In this study, instrument validity testing activities were conducted by expert lecturers and school principals with expertise in their respective fields. The validation data are presented below.

Table 6. Results of Instrument Validity Test by Principal and Teachers

No	Validity Test Results	Expert Lecturer	Category	Principal	Category
1	Media Validity	91.67%	Very Worthy	89%	Very Worthy
2	Material Validity	84.40%	Very Worthy	89.55%	Very Worthy
3	Language Validity	88.89%	Very Worthy	89.64%	Very Worthy
4	Teacher Comprehension Test Instrument	88.89%	Very Worthy	-	-
5	Teacher Comprehension Self-Assessment Questionnaire	83.33%	Very Worthy	-	-

After being validated by experts and revised, the next step was a small group trial involving 12 teachers. The purpose of this trial was to determine the practicality of the media from a user perspective. Teachers were given the opportunity to directly try the SI MOPEM media and were then asked to provide feedback via a questionnaire. The results of the media practicality test are shown below.

Table 7. Practicality Test Results

No	Teacher Understanding Indicators	Total Score	Average Score	Percentage
1	Translasi	173	14.42	36.04
2	Interpretasi	176	14.67	36.67
3	Ekstrapolasi	90	7.50	18.75
Total		439	36.58	91.46%

Based on Table 7, the practicality test yielded a final percentage of 91.46%, which falls into the "Very Practical" category. This indicates that the SI MOPEM media is considered capable of facilitating teachers' understanding of the syntax of various learning models clearly and interactively. The final step in the development phase was an effectiveness test using a one-group pretest-posttest design. Before the questions were distributed to teachers, they were first tested for validity and reliability. The instrument consisted of 18 essay questions. The results of the validity and reliability tests are shown in the following table.

Table 8. Validity Test Results

Criteria	Question Items	Total
Valid	3, 4, 6, 7, 10, 11, 13, 14, 15, 16, 17, 18	12
Invalid	1, 2, 5, 8, 9, 12	6

Based on Table 8, it can be seen that of the 18 items tested, 12 (66.67%) met the validity criteria. Meanwhile, 6 items (33.33%) were declared invalid. Valid items will be retained for use in the next phase of the research, while invalid items will be eliminated.

Table 9. Reliability Test Results

Cronbach's Alpha	Items
.934	12

Based on Table 8, the Cronbach's Alpha value obtained was 0.934 for a total of 12 items, all 12 of which were declared valid in the previous validity test. This indicates that the teacher understanding test instrument has a very high level of reliability, making it a reliable and consistent measure of teacher understanding. Next, at this stage, 50 teachers from five schools were given a pretest to determine their initial understanding of the learning model. Teachers studied the SI MOPEM media for a specified period, then received a posttest to measure their understanding improvement after using the media. The results of the data analysis are presented below.

Table 10. Normality Test Results

Tests of Normality						
	Kolmogorov-Smirnov ^a			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
PRE	.139	50	.017	.963	50	.116
POST	.133	50	.027	.960	50	.085

Based on Table 10, the results of the Shapiro-Wilk normality test indicate that the significance value for the pretest data is 0.116 and the posttest is 0.085, both greater than 0.05. Therefore, it can be concluded that the data are normally distributed, thus meeting the requirements for conducting a parametric statistical test, namely the paired sample t-test.

Table 11. Paired Sample t-Test Results

Paired Samples Test									
		Paired Differences			t	df	Sig. (2-tailed)		
		95% Confidence Interval of the Difference							
		Mean	Std. Deviation	Std. Error Mean	Lower	Upper			
Pair 1	Pretest-Posttest	-30.12000	4.18276	.59153	-31.30873	-28.93127	-50.919	49	.000

Based on Table 11, the significance value obtained is 0.000 (<0.05), thus it can be concluded that there is a significant difference between the pretest and posttest results. This means that the use of the AR SI MOPEM media significantly improves teachers' understanding of 21st-century learning models. Furthermore, to determine the effectiveness of this improvement, an N-Gain test was performed to determine whether the teachers' understanding was low, medium, or high.

Table 12. N-gain Test Results

Descriptive Statistics					
	N	Minimum	Maximum	Mean	Std. Deviation
Ngain	50	.33	.92	.6299	.09337
NGain_persen	50	33.33	92.11	62.9942	9.33654
Valid N (listwise)	50				

Based on Table 12, the N-Gain value was 0.63 or 63%, which is considered moderate. This indicates that the use of the SI MOPEM AR media was quite effective in improving teachers' understanding of 21st-century learning models. Thus, the development stage successfully produced a feasible, practical, and effective media, ready for dissemination in the next stage.

Disseminate

The disseminate stage is the final stage in the 4D development model, aiming to introduce and distribute the product, which has been declared feasible, practical, and effective, to a wider audience. During this stage, researchers conducted outreach and training for elementary school teachers in Serang Regency to ensure they understood how to use the SI MOPEM AR media. This activity began with a meeting of the teacher working groups (KKG) in the target school clusters. During this outreach activity, researchers provided a presentation on how to operate the application, from installing the SI MOPEM application and using markers to displaying visualizations of the learning model steps through 3D animations. In addition to the presentation, teachers were also given the opportunity to try the application independently using their respective smartphones. Teachers scanned the provided markers to view animations of the learning model syntax, such as PBL, PjBL, and DL. This session was designed to provide a realistic and interactive learning experience, allowing teachers not only to understand the theory but also to see visual representations of each step in the learning model. Documentation of the outreach process and hands-on practice is shown in the following image.

**Image 6.** Socialization Process and AR SI MOPEM Practices

In addition to dissemination at the school cluster level, researchers also published research results through scientific articles in reputable journals, making this media accessible to a wider audience, including teachers, principals, and education officials. This step is expected to broaden the impact of the SI MOPEM media, allowing teachers from various regions to utilize this innovation

independently. Through this dissemination stage, the SI MOPEM media not only becomes an innovative product beneficial to target schools but also serves as a means of professional development for teachers in understanding and implementing a variety of learning models relevant to the demands of the 21st century.

This study aims to find a more effective solution to improve teachers' understanding of 21st-century learning models. Based on initial findings, it was found that although teachers were familiar with learning models such as PBL, PjBL, and DL, their understanding of the syntax and implementation steps was still limited. Many teachers tend to revert to lecture-based methods due to an insufficient in-depth understanding, resulting in monotonous learning and low student participation. This situation highlights the need for a media that can visualize the steps of learning models interactively and practically (Widana & Laksitasari, 2023).

In response to this issue, the researcher developed AR media SI MOPEM, designed to display 3D animations of learning model syntax. This media allows teachers to understand the sequence of steps in learning models more clearly and thoroughly. The research instruments, including questionnaires and teacher comprehension tests, were carefully prepared and validated to align with the research objectives, ensuring that the measurement of the media's feasibility and effectiveness could be trusted. The media development process in the Develop stage showed that SI MOPEM received "very feasible" ratings from both experts and users. Practicality tests conducted by teachers resulted in a score of 91.46%, indicating that the media greatly assisted teachers in understanding the syntax of learning models. Teacher comprehension tests also showed a significant improvement between pretest and posttest, with an N-Gain of 0.63 (moderate), proving that the media is quite effective in enhancing teachers' understanding.

The final stage, Disseminate, was carried out through teacher training and the Teacher Working Group (KKG) forums, where teachers tried the media directly and provided positive feedback. Teachers considered the media easy to use, engaging, and supportive in improving their understanding of learning models. Academic publications were also conducted to expand the reach of the media's utilization.

Overall, the development of AR SI MOPEM has proven to be an effective solution for improving teachers' understanding of 21st-century learning models. The media is not only feasible and practical but also supports teachers in independently applying learning models, enabling the creation of innovative, interactive, and 21st-century skills-oriented learning. The results of this study align with the findings of Ramadhani et al. (2025); Yusriani et al. (2020), which stated that teachers still have difficulty understanding the syntax of learning models and tend to revert to lecture methods. It also supports the views of (Budirahayu & Saud, 2023; Oktaviani, Nurma'ardi, et al., 2023) that a deep understanding of learning models is key to implementing 21st-century learning. The innovation and novelty of this study lie in the development of an AR-based media called SI MOPEM, which presents the syntax of learning models such as PBL, PjBL, and DL in the form of interactive three-dimensional animations to help teachers understand learning steps visually and practically. The results indicate that this media is highly practical (91.46%) and quite effective in improving teachers' understanding (N-Gain 0.63). Theoretically, this study contributes to the development of technology-based learning theory by demonstrating that the use of AR can serve as an effective means to enhance teachers' conceptual understanding of learning model syntax (Widana et al., 2021).

Practically, the study has a positive impact in the field as it helps teachers overcome difficulties in understanding and applying 21st-century learning models, increases their independence, and enriches the variety of learning media in elementary schools. However, the study has limitations,

including a small respondent scope (50 teachers from five schools), not measuring the impact on classroom teaching practices, and covering only three learning models. Therefore, it is recommended that future research expand the subject pool, develop a version of SI MOPEM with self-reflection and evaluation features, and examine its impact on student learning outcomes so that this media can be utilized more broadly and sustainably to support the transformation of 21st-century learning.

Conclusion

This study concludes that the Augmented Reality (AR) media, SI MOPEM, is effective in enhancing elementary school teachers' understanding of 21st-century learning models such as PBL, PjBL, and DL. Through the development of the 4D model, SI MOPEM helps teachers grasp the syntax and implementation of learning models more concretely and interactively. Before using the media, teachers only recognized the names of the learning models without fully understanding their procedures. However, after using SI MOPEM, their ability to explain and apply these models in the classroom improved. Theoretically, this study reinforces that AR technology can facilitate the understanding of complex pedagogical concepts, while practically, SI MOPEM provides ease and engagement for teachers in self-directed learning. The recommendations from this study are to expand the scale of testing, conduct ongoing teacher training to optimize digital learning transformation, and develop SI MOPEM by adding features or integrating it with other platforms.

Acknowledgements

The researchers would like to express their deepest gratitude to KEMDIKTISAINTEK and DPPM for their support through the PDP grant program with master contract number 125/C3/DT. 05.00/PL/2025 along with its derivative contracts 8080/LL4/PG/2025 and 3093/H.K.3.4/01-UPG/VI/2025. In addition, the researchers would also like to thank the schools involved, Primagraha University, and all parties who cannot be mentioned individually for their support and facilities, which made this research possible.

Bibliography

- Ahmadin, Nehru, & Iqbal. Muh. (2023). Persiapan guru dalam menghadapi tantangan di era society 5.0 di SMAN 1 Wawo (Teacher preparation to face challenges in the society era). *Jurnal Pendidikan Dan Ilmu Sosial*, 2(2), 136–141.
- Aini, H. N., & Fathoni, A. (2020). Pengembangan Lembar Kerja Peserta Didik (LKPD) Matematika Berbasis Budaya Lokal Siswa Sekolah Dasar (Development of Mathematics Student Worksheets (LKPD) Based on Local Culture for Elementary School Students). *Jurnal Basicedu*, 6(4), 6167–6174. <https://doi.org/https://doi.org/10.31004/basicedu.v6i4.3191>
- Akram, A., & Maryam, K. (2021). Pengembangan media interaktif berbasis blog di SMA negeri 1 Tommo (Development of blog-based interactive media at SMA Negeri 1 Tommo). *Jurnal Literasi Digital*, 1(2), 139–147. <https://doi.org/https://doi.org/10.54065/jld.1.2.2021.36>
- Alimah, S., Wijaya, S., & Nurma'ardi, H. D. (2024). Pengaruh model pembelajaran kooperatif tipe two stay two stray terhadap keaktifan belajar siswa kelas V di SDN Ragas 1 (The influence of the two stay two stray type cooperative learning model on the learning activity of fifth grade students at SDN Ragas 1). *Arus Jurnal Sosial Dan Humaniora (AJSH)*, 4(3), 1757–1762. <https://doi.org/https://doi.org/10.57250/ajsh.v4i3.745>
- Aminah, A., Hairida, H., & Hartoyo, A. (2022). Penguatan pendidikan karakter peserta didik melalui pendekatan pembelajaran kontekstual di sekolah dasar (Strengthening students' character education through a contextual learning approach in elementary schools). *Jurnal Basicedu*,

- 6(5), 8349–8358. <https://doi.org/https://doi.org/10.31004/basicedu.v6i5.3791>
- Arsyad, H., & Sauri, S. (2024). Landasan filosofi pendidikan dan konsep mendidik (The philosophical basis of education and the concept of education). *Jurnal Ilmiah Profesi Pendidikan*, 9(3), 1585–1596. <https://doi.org/https://doi.org/10.29303/jipp.v9i3.2579>
- Aryanto, S., Hartati, T., Maftuh, B., & Darmawan, D. (2022). Sastra anak berbasis ecopreneurship sebagai muatan pembelajaran literasi finansial di sekolah dasar (Ecopreneurship-based children's literature as financial literacy learning content in elementary schools). *Jurnal Cakrawala Pendas*, 8(3), 722–737. <https://doi.org/https://doi.org/10.31949/jcp.v8i3.2569>
- Asoodar, M., Janesarvatan, F., Yu, H., & de Jong, N. (2024). Theoretical foundations and implications of augmented reality, virtual reality, and mixed reality for immersive learning in health professions education. *Advances in Simulation*, 9(1), 1–19. <https://doi.org/10.1186/s41077-024-00311-5>
- Astuty, W., & Suharto, A. W. B. (2021). Desain perencanaan pelaksanaan pembelajaran pendidikan agama islam daring dengan kurikulum darurat (Design of planning for the implementation of online Islamic religious education learning with an emergency curriculum). *Jurnal Penelitian Pendidikan Islam*, 9(1), 81–96. <https://doi.org/https://doi.org/10.36667/jppi.v9i1.624>
- Budirahayu, T., & Saud, M. (2023). Pedagogical innovation and teacher collaborations in supporting student learning success in Indonesia. *Cogent Education*, 10(2), 1–16. <https://doi.org/https://doi.org/10.1080/2331186X.2023.2271713>
- Carolina, Y. Dela. (2022). Augmented reality sebagai media pembelajaran interaktif 3d untuk meningkatkan motivasi belajar siswa digital native (Augmented Reality as a 3D Interactive Learning Media to Increase Learning Motivation of Digital Native Students). *Ideguru: Jurnal Karya Ilmiah Guru*, 8(1), 10–16. <https://doi.org/https://doi.org/10.51169/ideguru.v8i1.448>
- Chen, H. H., & Yuan, Y. H. (2021). The study of the relationships of teacher's creative teaching, imagination, and principal's visionary leadership. *SAGE Open*, 11(3), 1–15. <https://doi.org/10.1177/21582440211029932>
- Ernawati, E., Evitasari, A. I., & Nurma'ardi, H. D. (2024). Pengaruh model pembelajaran make a match pada hasil belajar ipa materi sistem pencernaan manusia di kelas V SD negeri lopang domba (The influence of the make a match learning model on science learning outcomes on the human digestive system material in gra. *Arus Jurnal Sosial Dan Humaniora*, 4(3), 1690–1696. <https://doi.org/https://doi.org/10.57250/ajsh.v4i3.754>
- Gandolfi, E., & Ferdig, R. E. (2025). Exploring the relationship between motivation and augmented reality presence using the augmented reality presence scale (ARPS). *Educational Technology Research and Development*, 73, 793–814. <https://doi.org/10.1007/s11423-025-10446-5>
- Irwanto, Y., & Nisa, A. N. S. (2022). Efektivitas pembelajaran IPS menggunakan model student facilitator and explaining pada kelas VII SMPN 24 Semarang (The effectiveness of social studies learning using the student facilitator and explaining model in class VII of SMPN 24 Semarang). *Sosiolium: Jurnal Pembelajaran IPS*, 4(1), 48–55. <https://doi.org/https://doi.org/10.15294/sosiolium.v4i1.55989>
- Jensen, M. T., Solheim, O. J., & Olsen, E. (2024). Leader support in relation to teacher self-efficacy, classroom emotional climate and students' literacy skills in elementary school. *Scandinavian Journal of Educational Research*, May, 1–14. <https://doi.org/10.1080/00313831.2024.2348451>
- Laia, J. K. (2023). Upaya peningkatan hasil belajar ppkn melalui penerapan model pembelajaran listening teams di kelas VIII SMP negeri 1 o'o'u tahun pembelajaran 2022/2023 (Efforts to improve civics learning outcomes through the implementation of the listening teams learning. *Civic Society Research and Education: Jurnal Pendidikan Pancasila Dan Kewarganegaraan*, 4(1), 28–41. <https://doi.org/https://doi.org/10.57094/jpkn.v4i1.820>
- Lambrecht, A., Baumgarth, C., & Henseler, J. (2025). Holistic augmented reality brand equity

- (HARBE) model: building customer-based brand equity through augmented reality. *Journal of Brand Management*, 1–17. <https://doi.org/10.1057/s41262-025-00381-4>
- Lestari, R., Jasiah, J., Rizal, S. U., & Syar, N. I. (2023). Pengembangan media berbasis video pada pembelajaran IPAS materi permasalahan lingkungan di kelas V SD (Development of video-based media in science learning on environmental issues in grade V of elementary school). *Jurnal Holistika*, 7(1), 34. <https://doi.org/10.24853/holistika.7.1.34-43>
- Li, C., Zhu, L., Zhang, H., & Song, A. (2025). Efficient social distance maintenance with augmented reality. *Virtual Reality*, 29(1), 1–13. <https://doi.org/10.1007/s10055-025-01102-7>
- Liu, S., & Phelps, G. (2020). Does teacher learning last? Understanding how much teachers retain their knowledge after professional development. *Journal of Teacher Education*, 71(5), 537–550. <https://doi.org/10.1177/0022487119886290>
- Maisyaroh, Budi Wiyono, B., Hardika, Valdez, A. V., Mangorsi, S. B., & Canapi, S. P. T. (2021). The implementation of instructional supervision in Indonesia and the Philippines, and its effect on the variation of teacher learning models and materials. *Cogent Education*, 8(1). <https://doi.org/https://doi.org/10.1080/2331186X.2021.1962232>
- Mirza, F., Muhammadi, A., & Yulianawati, D. (2025). Peningkatan hasil belajar bahasa Indonesia melalui model problem based learning pada siswa kelas V sekolah dasar (Improving Indonesian language learning outcomes through problem-based learning models in fifth grade elementary school students). *Edukasi Tematik: Jurnal Pendidikan Sekolah Dasar*, 6(2), 92–99. <https://doi.org/https://doi.org/10.59632/edukasitematik.v6i2.507>
- Nguyen, P., Webel, C., Yeo, S., & Zhao, W. (2022). Elementary teachers' agency: The role of perceived professional space and autonomy. *Journal of Curriculum Studies*, 54(5), 665–686. <https://doi.org/https://doi.org/10.1080/00220272.2022.2081821>
- Nurma'ardi, H. D., & Kuswaty, M. (2023). Keefektifan pembelajaran problem based learning terhadap kemampuan berpikir kritis dan motivasi belajar siswa sekolah dasar (The effectiveness of problem-based learning on critical thinking skills and learning motivation of elementary school students). *JIDeR*, 3(4), 139–146. <https://doi.org/https://doi.org/10.53621/jider.v3i4.253>
- Oktaviani, A. M., Makrum, A., Nurhasanah, N., & Sarivah, I. (2023). The influence of self- concept on the students' achievement motivation in 4. *JPSD (Jurnal Pendidikan Sekolah Dasar)*, 9(1), 1–13. <https://doi.org/https://dx.doi.org/10.30870/jpsd.v9i1.18847>
- Oktaviani, A. M., Nurma'ardi, H. D., & Rokmanah, S. (2023). *Model pembelajaran interaktif*. Mitra Ilmu.
- Pratama, A. R., & Sukirman, S. (2023). Development of augmented reality multiple markers application used for interactive learning media. *Sinkron*, 8(3), 1326–1334. <https://doi.org/https://doi.org/10.33395/sinkron.v8i3.12482>
- Pujiarti, E., Purba, F. D., Ahmadi, K. D., & Mulya, S. (2023). Implementasi kurikulum merdeka dalam meningkatkan kompetensi profesionalisme guru di SMKS 2 tamansiswa pematangsiantar (Implementation of the independent curriculum in improving the professional competence of teachers at SMKS 2 Tamansiswa Pematangsiantar). *Jurnal Penelitian, Pendidikan Dan Pengajaran: JPPP*, 4(1), 11–18. <https://doi.org/https://doi.org/10.30596/jppp.v4i1.13586>
- Ramadhani, Z. T., Darmiany, & Rahmatih, A. N. (2025). Analisis kesulitan guru dalam menerapkan model pembelajaran problem based learning pada mata pelajaran IPAS di kelas V SDN 13 Mataram (Analysis of teacher difficulties in implementing the problem-based learning model in the science subject in class V of S. *Pendas: Jurnal Ilmiah Pendidikan Dasa*, 10(1), 111–134. <https://doi.org/https://doi.org/10.23969/jp.v10i01.23632>
- Rosidah, S., Fitriani, & Rosita. (2024). Penerapan media augmented reality dalam meningkatkan pemahaman materi ibadah di mis bachrul huda (The Application of Augmented Reality Media to Improve Understanding of Worship Material at MIS Bachrul Huda). *EduSpirit: Jurnal Pendidikan Kolaboratif*, 1(1), 520–525.

- <https://doi.org/https://doi.org/10.57218/jupeis.Vol2.Iss3.770>
- Santoso, J. T. (2021). *Augmented reality (AR)* (Issue 75). Penerbit Yayasan Prima Agus Teknik.
- Widana, I. W., Sopandi, A. T., Suwardika, I. G. (2021). Development of an authentic assessment model in mathematics learning: A science, technology, engineering, and mathematics (STEM) approach. *Indonesian Research Journal in Education*, 5(1), 192-209. <https://doi.org/10.22437/irje.v5i1.12992>
- Widana, I. W., & Laksitasari, B. D. (2023). Improving students' learning outcomes on circle equation material using GeoGebra software. *Indonesian Journal of Educational Development (IJED)*, 4(1), 32-39. <https://doi.org/10.59672/ijed.v4i1.2792>
- Yang, X., Cheng, P. Y., & Huang, Y. M. (2021). Understanding teacher learning through teacher-created knowledge products and transactions. *SAGE Open*, 11(3). <https://doi.org/https://doi.org/10.1177/21582440211032659>
- Yusriani, Y., Arsyad, M., & Arafah, K. (2020). Kesulitan guru dalam mengimplementasikan model pembelajaran berbasis proyek pada mata pelajaran fisika di SMA kota Makassar (Teachers' difficulties in implementing project-based learning models in physics subjects in high schools in Makassar City). *Prosiding Seminar Nasional Fisika PPs UNM*, 2, 138–141.
- Zetriuslita, Z., & Alzaber, A. (2021). Model model pembelajaran sesuai tuntutan kurikulum 2013 (Pelatihan untuk guru-guru SMP kampar kiri hilir) (Learning models according to the demands of the 2013 (curriculum training for Kampar Kiri Hilir middle school teachers). *Community Education Engagement Journal*, 2(1), 30–37. <https://doi.org/10.25299/ceej.v2i1.5981>